CYCLING OF VRLA LEAD-ACID BATTERIES FOR USE IN UNINTERRUPTIBLE POWER SUPPLIES AND MEASUREMENT OF FAILED BATTERIES

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Abstract: This article deals with study on the influence of cycling of batteries with regard to their parameters. Electro-chemical reactions which take part in battery cells are described. This paper also offers a measurement scheme for automated measuring workstation. Furthermore, results of measurements are being presented on measured parameters of chosen batteries. Comparison of the measurements results and datasheet values is included. Conclusion sums up parameters of chosen batteries and their feasibility for further usage in Uninterruptible Power Supply as a crucial part of critical infrastructure.

Keywords: battery cycling, battery failure modes, capacity loss, lead-acid battery, Uninterruptible Power Supply, VRLA

1 INTRODUCTION

Batteries in general are essential for supplying current in all kind of devices which are not connected to electrical grid. Nowadays there is also a high increase in using batteries for storaging electrical power. They might also be used as solar battery storage or for providing power in Uninterruptible Power Supply (UPS).

There are many types of batteries, but one of the most important one is the oldest – lead-acid battery. This battery type has a lot of advantages over other battery types. It is the best in terms of reliability and working capabilities, it is also capable to withstand long term inactivity with or without a solvent. It offers the best value for power and energy per watt hour. Technology of production is well known so this battery type is quite inexpensive [3].

Lead-acid battery is not suitable for applications with regard to weight, also the weight -energy ratio is low. Its life cycle is quite limited and likewise repeated deep cycling highly reduces battery life [4].

This chemical power supply source is based on reaction of lead dioxide (PbO_2) on the positive electrode and pure lead (Pb) on the negative electrode [3]. Electrolyte is a mixture of water and sulfuric acid (30 – 40 %), specific gravity of this mixture is around 1.28 g/cm^3 [5].

Electrochemical reactions on positive electrodes:

$$\mathrm{PbO_{2\,(s)}} \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftarrows}} \mathrm{Pb^{2+}} + 2\,\mathrm{H_2O} \tag{1}$$

$$\mathrm{Pb^{2+}_{(aq)}} + \mathrm{SO_4{}^{2-}{}_{(aq)}} \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftarrows}} \mathrm{PbSO_{4\,(s)}} \tag{2}$$

Electrochemical reactions on negative electrodes:

$$Pb_{(s)} \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftarrows}} Pb^{2+}_{(aq)} + 2\,e^{-} \tag{3}$$

$$Pb^{2+}_{(aq)} + SO_4{}^{2-}{}_{(aq)} \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftarrows}} PbSO_{4(s)} \tag{4}$$

2 MEASUREMENT SCHEME

For this experiment, following 4 batteries from 3 different vendors were chosen. To minimize possible negative effect of damaged cell in battery, 3 batteries of the same type and vendors were measured at the same time. Batteries are VRLA (Valve Regulated Lead Acid) types rated at least at 7 Ah.

Before starting this experiment, voltage at battery terminals was measured, values are shown in Table 1. Highest voltage difference (433 mV) was measured between battery number 6 and battery number 1. After that, batteries were left on float voltage for three days.

Batteries were being discharged by constant current 0.25 C (1.75 A) until reaching cut-off voltage 10.2 V. When the battery voltage dropped under 10.2 V, batteries were immediately switched into defined charging mode. Charging current was equal to 0.35 C (2.5 A) with voltage limitation of 14.7 V. Battery was charged, until accepting 104 % of previously drained charge.

Normal temperature and pressure (NTP) and forced airflow were provided by air conditioning of the room to the pre-set temperature of 20 °C. This experiment lasted about 1 month and the batteries made around 120 cycles, automated measurement station obtained values every 30 seconds [2].

Table 1: Voltage at battery terminals before the experiment was launched.

battery type	**Panasonic(LC-R127)**			**EnerSys(NP7-12T)**			**CTM(CT7-12L)**			**CTM(CTV7-12)**		
battery number	1	2	3	4	5	6	7	8	9	10	11	12
battery voltage [V]	12.39	12.45	12.40	12.77	12.79	12.82	12.88	12.85	12.87	12.66	12.62	12.62

3 BATTERY CYCLING

Long-term battery cycling results are shown in Fig. 1. Capacity loss of battery number 3 (Panasonic) is evident, capacity loss of other two batteries is not that steep. All Panasonic batteries tend to have some increase in capacity due to formation of the battery. Their peak occurs at 20th cycle. For instance battery number 1 difference between capacity peak and last cycle is 0.35 Ah, which is around 5 %.

All EnerSys batteries tend to lose capacity in the same way. At early beginning they lose capacity rapidly, but after around 40 cycles they tend to stop losing capacity or even have some increase in capacity. All the EnerSys cells ended up with capacity around 4 Ah.

CTM battery CT7-12L is definitely the lowest quality battery type of this set. Two batteries (number 8 and number 9) rapidly lost almost all the capacity after around 40 cycles. Several tries to restore their rated capacity was made by leaving them on float charge at 14.7 V for the whole day.

Battery type of the same vendor CTM (CTV7-12) had stable performance, but even the initial capacity had just about 82 % of the rated capacity. This battery could not be recommend for use. In general battery is considered as worn out when it reaches 80 % of the rated capacity [6]. Formation of the battery is significant and peaked around 32nd cycle.

Unfortunately only one battery (number 1) out of this set is fulfilling capacity value and cycle life stated in manufacturer's datasheet.

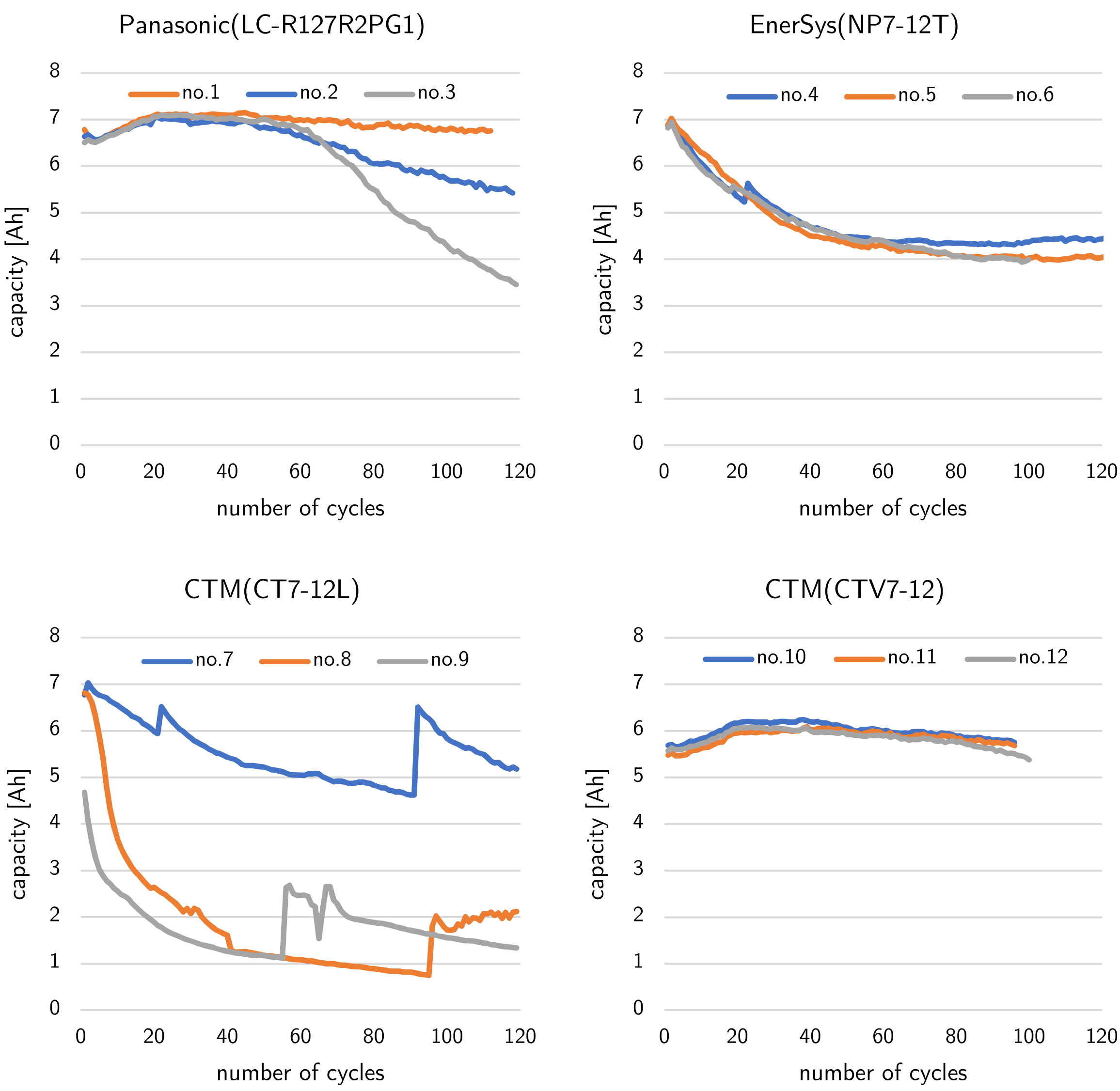

Figure 1: Long-term cycling of chosen VRLA batteries.

4 BATTERY FAILURES

With regard to enormous capacity loss of batteries number 8 and 9 and significant capacity loss of battery number 3, further test was launched. Batteries were discharged up to cut off voltage of 5 V. This discharge shows us possible failures of some cells in the battery. Figure 2 depicts significant voltage drops, which might be caused by shorted cells [6], [7], [8].

Figure 3 shows charging of batteries suspected from having shorted cell (battery number 8 and number 9). This figure also contains charge of battery with good performance and same number of cycles for comparison. With regards to those characteristics no shorted cell is present in the battery and the highly reduced capacity is probably caused by inaccurate production or possible impurities in material of the active mass [1], [3].

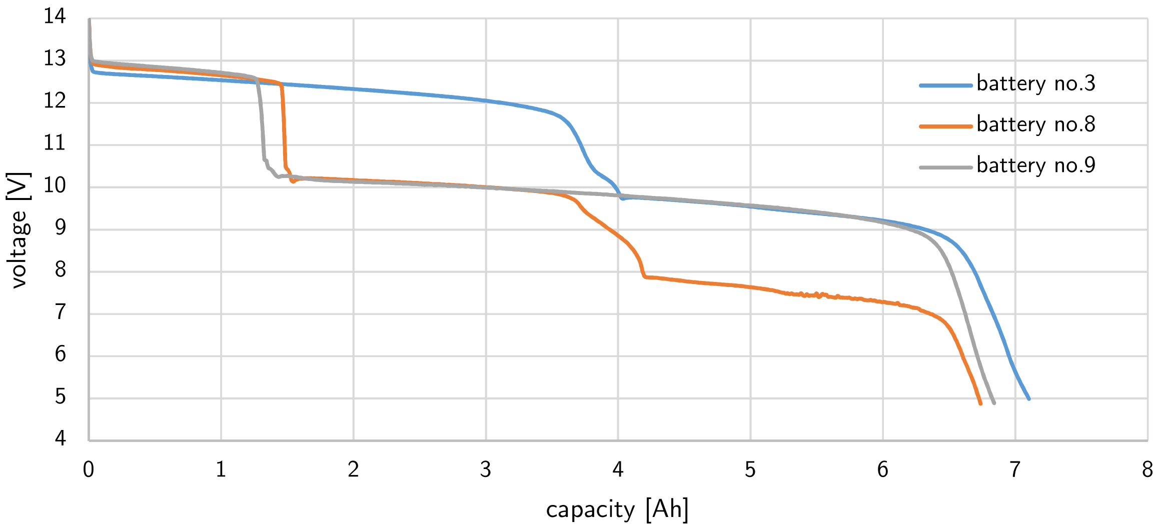

Figure 2: Deep discharge of chosen batteries with cut-off voltage equal to 5 V.

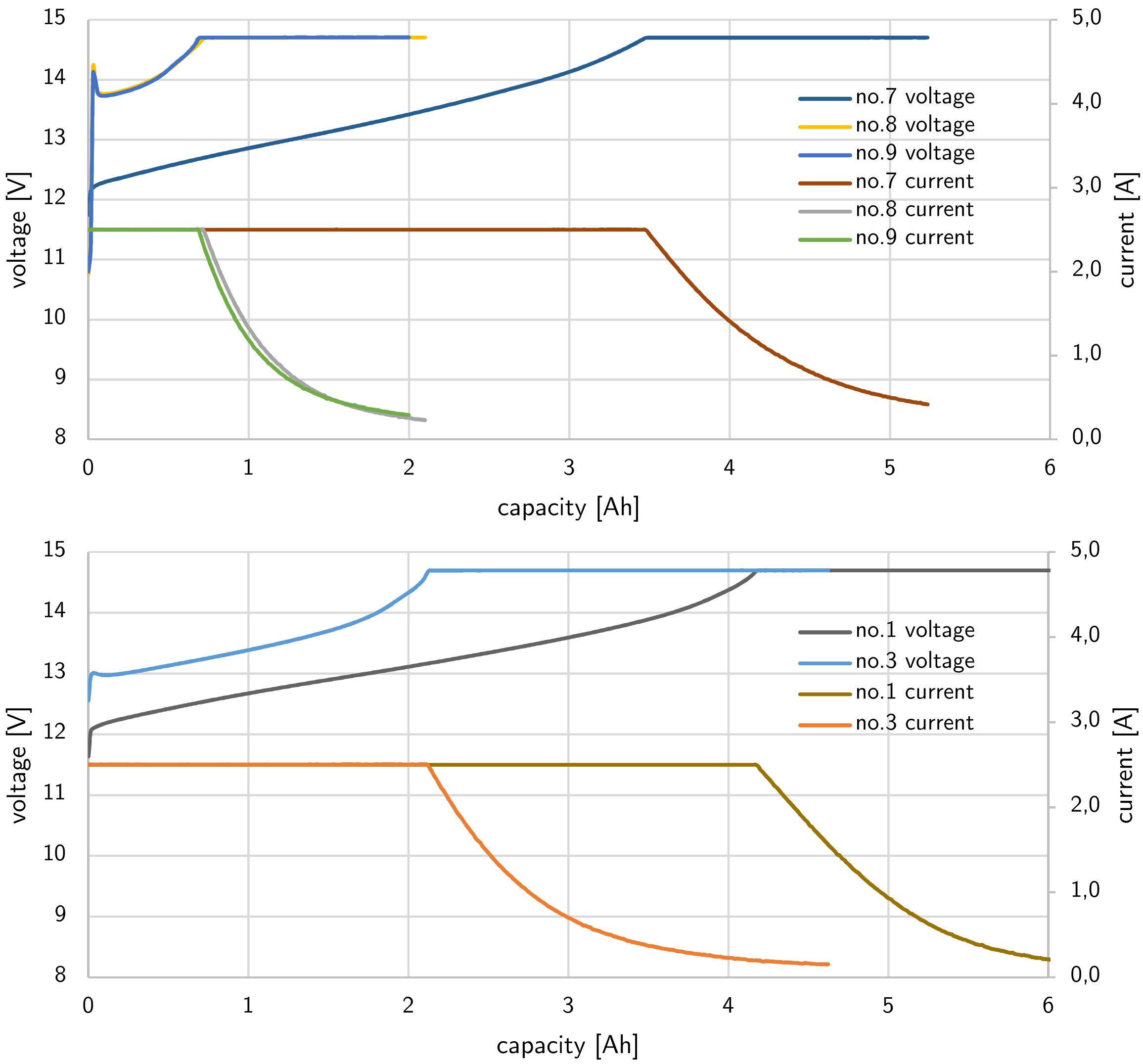

Figure 3: Charge graph of CTM battery (upper) and charge graph of Panasonic battery (lower).

5 CONCLUSION

This paper deals with experimental testing of lead-acid batteries which are commonly used as a crucial part of Uninterruptible Power Supplies. Long-term cycling of batteries shows that three battery types didn't conform the capacity parameter and number of cycles stated by the manufacturer in the datasheet. During the experiment three failed batteries were identified and were tested afterwards. Two batteries had problems with two cells, remaining one had a problem with only one cell. Outcome of this experiment is very worrying, since this type of battery is a crucial part of critical infrastructure and plays an important role in general security.

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